Impacts and Meteorite Organic Compounds

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The majority of meteorites that contain organic compounds are thought to originate in the asteroid belt. Impacts among asteroids and impacts between asteroids and comets with the planets generate heat and pressure that may have altered or destroyed preexisting organic matter (depending upon impact velocities). Very little is known about the impact-related chemical evolution of organic matter relevant to this stage of the cosmic history of biogenic elements and compounds. At Ames Research Center, research continues in an effort to understand the effects of impacts on organic compounds.

One experimental approach is to subject mixtures of organic compounds, embedded in the matrix of a meteorite, to simulated hypervelocity impacts using a vertical gun. By choice of suitable targets and projectile materials, the compounds are subjected to simulated impacts, resulting in various pressures in the range of 100 to 400 kilobar. Each pressure can then be converted by mathematical equations into the corresponding impact velocity that an actual asteroid or meteorite would have experienced. Most of these velocities are too high to obtain in the laboratory. After the laboratory impacts, the products are analyzed to determine the degree of survival of the organic compounds.

Four classes of organic compounds, known to be indigenous to carbonaceous meteorites, have been studied: organic sulfur, organic phosphorous, polyaromatic hydrocarbons, and amino acids. The sulfur compounds were sulfonic acids containing one to four carbons. The phosphorous compounds were phosphonic acids, also containing one to four carbons.

Results show that over the range of pressures the general trend is that the survival rates of compounds are inversely proportional to impact pressure (impact velocity). However, at lower pressures, 100 to 200 kilobar (approximately 1 to 2 kilometers per second (km/sec)), the sulfonic acids containing only one or two carbons show nearly complete survival. There was a significant drop in survival rates at approximately 300 kilobar for all organic sulfur and phosphorous compounds. Pressures of 300 to 400 kilobar (4 to 5 km/sec) resulted in survival rates of approximately 20 to 30% for all one- and two-carbon compounds, while the three- and four-carbon compounds survived at rates of approximately 0 to 10%. In the case of polyaromatic hydrocarbons and amino acids, a similar trend of decreasing survival rates with increasing pressure was observed. However, these two groups were less stable than the sulfur compounds at lower pressures.

These results indicate that significant amounts of meteoritic organic compounds would have survived impacts within the asteroid belt throughout solar-system history. In the context of asteroid impacts on Earth, the results also suggest that most of organic compounds would have survived in objects that experienced impact velocities near or below 4 to 5 km/sec.

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Biogeochemistry of Early Earth Photosynthetic Ecosystems: Production of Hydrogen and Carbon Monoxide

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For the first three-quarters of its history, Earth's biosphere consisted exclusively of microbial life. Most of this period was dominated by photosynthetic microbial mats, highly complex and organized communities of microorganisms that once covered the Earth. For two billion years, these mats were the primary biologic agents of global environmental change (for example, the oxygenation of the atmosphere) and the crucible for evolution of the complex macroscopic life forms we know today. Ames' Early Microbial Ecosystems Research Group studies the biology, chemistry, and geology of closely related modern microbial mats in order to better understand the important role played by their ancient counterparts.

A key focus is to understand how the chemistry of the mat influences, and is influenced by, the collective activities of the constituent bacteria. The sunlit surface layer of the mat harbors the highest population of active bacteria, is the most productive, and has the most direct interaction with the outside environment. Within this layer, concentrations of two gaseous products of microbial metabolism, hydrogen and carbon monoxide, vary in dramatic fashion during the course of one day (as shown in figure 1). The light-driven liberation of carbon monoxide has not been previously observed in mat communities. Given the widespread distribution of mats on early Earth, this light-driven liberation of carbon monoxide could have represented a significant but unrecognized contribution to the ancient atmosphere. Hydrogen concentrations in the mat vary by a factor of 10,000 or more during one day/night cycle. This variation is much greater than the variation that the Earth's surface environment on the whole has experienced during its entire history.

This variation in hydrogen is especially important in the context of the microbiology and chemistry of the mat. Many of the bacteria in the mat utilize hydrogen as an essential means of transferring chemical energy and "information" to one another. The dramatic daily variations in hydrogen may extensively influence the way in which these organisms interact and function as a collective whole. An important key to global change in the ancient environment, and to half of the evolution of life on Earth, may thus lie in the roller-coaster chemistry of microbial mats.

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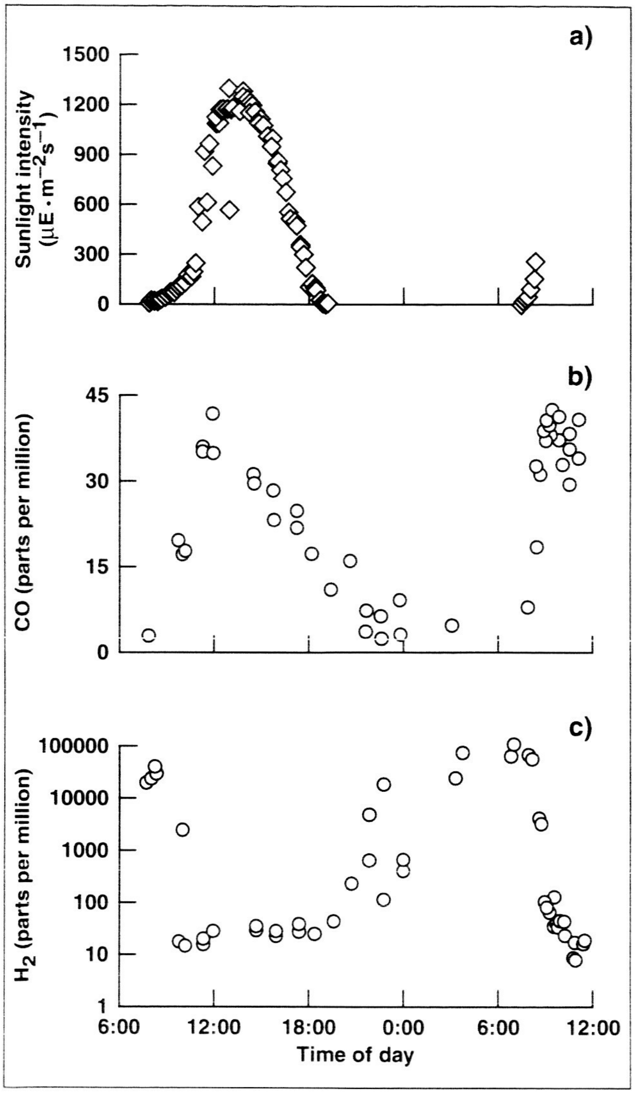

Fig. 1. Light intensity (a), carbon monoxide concentration (b), and hydrogen concentration (c) at the surface of a microbial mat from Baja, Mexico, during the course of one diel (24-hour day/night cycle). These graphs illustrate the dramatic light-driven chemistry generated by bacteria within the microbial mat. The chemical environment shown here experiences a greatly more substantial shift in conditions over a few hours than the Earth's atmosphere has during its entire history.